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Status of GaAs/Ge Solar Cells*

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This is a brief status report on GaAs/Ge solar cell work at ASEC.

Substrates

Germanium has good lattice and thermal match to GaAs, allowing epitaxial growth of high quality GaAs and AlGaAs layers. The higher mechanical strength of Ge provides thinner (lighter) cells of useable areas. The combination of higher power/unit area and power/unit mass available from thin GaAs/Ge cells is of interest to many satellite missions using lightweight arrays, and in some cases requiring high survivability.

Present Ge substrates cost less than GaAs substrates. Additional significant cost reductions are emerging from the greater ease of growing good quality, large area crystals from an element rather than a compound, and as a result of the increasing production volume of GaAs/Ge cells.

Cell Design

Figure 1 shows a cross-section of a generic GaAs/Ge cell. All of the high efficiency structures developed for GaAs/GaAs cells (thin base, BSF, thin emitter and windows) have been demonstrated successfully for GaAs/Ge cells.

The GaAs/Ge interface can be photovoltaically active, providing additional voltage. However, to facilitate immediate acceptance for production quantities of GaAs/Ge cells, ASEC has ensured that the GaAs/Ge interface is inactive. The inactive-Ge cell retains the performance of the best GaAs/GaAs cells, namely high efficiency, low temperature coefficients, and good radiation resistance. The inactive-Ge structure is not sensitive to enhanced solar simulator output in the near infrared. Under true AM0 illumination, the inactive-Ge cells do not show kinked curves when the current collected near the GaAs/Ge interface is not matched to the current collected at the GaAs PN junction.

An additional advantage of the inactive Ge structure is the ability to relax the specified properties of the Ge substrate, and this also leads to significant cost reduction.

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Performance of GaAs/Ge Cells

The results quoted below are for GaAs/Ge cells grown and processed under typical production conditions. The GaAs layers were grown in high throughput MOCVD reactors (750-900cm^2 substrates per run).

AM0 Efficiency

The best efficiency measured for GaAs/Ge cells was 20.5% for a 2×2 cm^2 cell, 200μm thick (Figure 2). In production, 2×4 cm^2 cells, 200μm thick typically have 18.5% efficiency. 4×4 cm^2 cells have exceeded 19%. For this size, efficiencies up to 20.5% can be confidently projected from measurements on four 2×2 cm^2 cells formed on a single Ge substrate 4.5×4.5 cm^2 in size, because all four cells exceeded 20.3%.

In the MANTECH program, 4×4 cm^2 cells less than 90μm thick averaged 18.5%, and further increases are possible when the cell structure is optimized.

6×6 cm^2 cells, 90μm thick are being developed, in some cases with coplanar back contacts.

Bond Strength

Under bonding conditions which caused less than 2% change in cell output, both soldering and welding gave good adhesion (Tables 1, 2).

Cover-interconnected cells (CIC's), using both welded and soldered interconnects, have been supplied with typical output as shown in Table 3.

Radiation

GaAs/Ge cells show the same radiation performance as GaAs/GaAs cells with equivalent GaAs layer properties. Figure 3 shows output power versus 1 Mev electron fluence. The values shown are consistent with the GaAs PN junction depth (0.5μm). Further increase in radiation resistance will result from incorporation of shallower emitters.

Other Properties

Under temperature cycling, temperature - humidity exposure and photonexposure, GaAs/Ge cells have performed well (same as GaAs/GaAs cells). The performance for both substrates under high temperature exposure (long term or bursts) is determined by the contact metallization used. Even with the alloyed-Au metallization presently used, good stability to 400°C was obtained. To withstand higher temperatures, the metallization stack is being changed, to withstand exposure to temperatures around 600°C.

GaAs/Ge cells have shown high stability under application of high reverse-bias currents ($< I_{sc}$) for long times at high temperature, indicating good performance under array shadowing conditions. This enhanced stability over GaAs/GaAs cells is attributed to the presence of shunting paths resulting from the heteroepitaxy. These shunting paths do not limit achievement of high voltages and fill factors when the cell is forward biassed, in normal operation.

The solar absorptivity of GaAs/Ge cells is higher than that of GaAs/GaAs cells, because some wavelengths beyond the GaAs bandedge are absorbed in the Ge. Alpha values as low as 0.82 have been achieved.

Summary

With experience at increasing production levels, GaAs/Ge cells are proving their effectiveness for some demanding missions.

The experience in producing inactive-Ge structures should benefit parallel work on forming monolithic cascade cells using AlGaAs or GaAs top cell layers grown on Ge or other bottom cell materials. The adjustments needed to ensure that the GaAs/Ge interface is inactive are more likely to preserve the properties of a separately optimized bottom cell.

Table 1. GaAs/Ge CELL - SOLDERING TEST - PULL STRENGTHS

	Front Side		Back Side	
Cell No.	Force (Gr)	Failure Mode	Force (Gr)	Failure Mode
3	950	Cell Broke	1325	Divot
	1300	Cell Broke	875	Cell Broke
8	525	Cell Broke	1700	Divot
	1050	Cell Broke	750	Cell Broke
12	1350	Cell Broke	1150	Cell Broke
	1000	Cell Broke	1075	Cell Broke
15	775	Cell Broke	500	Cell Broke
	850	Cell Broke	525	Cell Broke
20	650	Divot	1075	Cell Broke
	650	Cell Broke	1325	Cell Broke
29	700	Cell Broke	975	Cell Broke
	1700	Cell Broke		Could Not Test
31	775	Divot	625	Cell Broke
	1450	Cell Broke	1400	Cell Broke
37	950	Cell Broke	975	Divot
	1300	Cell Broke	1450	Cell Broke
48	500	Cell Broke	1850	Cell Broke
	500	Divot		Could Not Test
58	675	Solder Separated	1425	Cell Broke
	725	Cell Broke		Could Not Test

Table 2. GaAs/Ge CELL - WELDING TEST - PULL STRENGTHS

	Front Side		Back Side	
Cell No.	Force (Gr)	Failure Mode	Force (Gr)	Failure Mode
21	300	Divot	425	Divot
	225	Divot	775	Divot
25	300	Divot	475	Cell Broke
	375	Divot	600	Cell Broke
33	150	Divot	800	Divot
	275	Divot	700	Divot
34	200	Divot	875	Divot
	540	Divot	800	Divot
51	250	Divot	600	Divot
	250	Cell Broke	900	Divot
53	575	Divot	680	Divot
	300	Divot	900	Divot
54	275	Divot	625	Divot
	275	Divot	900	Cell Broke
55	150	Divot	400	Cell Broke
	150	Divot	980	Divot
65	375	Cell Broke	450	Divot
	450	Cell Broke	250	Divot
67	150	Divot	725	Cell Broke
	275	Divot	900	Tab Broke

Table 3. **Photovoltaic Characterisitics (AMO) for CIC's (2x2cm^2 cells)**

Cell #	Voc mV	Isc mA	CFF %	EFF %
1	1005	128.0	80.5	19.1
2	1000	128.2	79.2	18.8
3	998	128.1	79.6	18.8
4	1000	128.0	79.6	18.8
5	1001	128.8	80.2	19.1
6	1003	127.3	79.8	18.8
7	994	127.1	74.0	17.3
8	998	128.2	78.5	18.6
9	1002	128.4	79.5	18.9
10	994	128.4	77.2	18.2
11	1005	127.5	78.1	18.5
12	1003	128.1	79.7	18.9
13	997	127.0	80.5	18.9

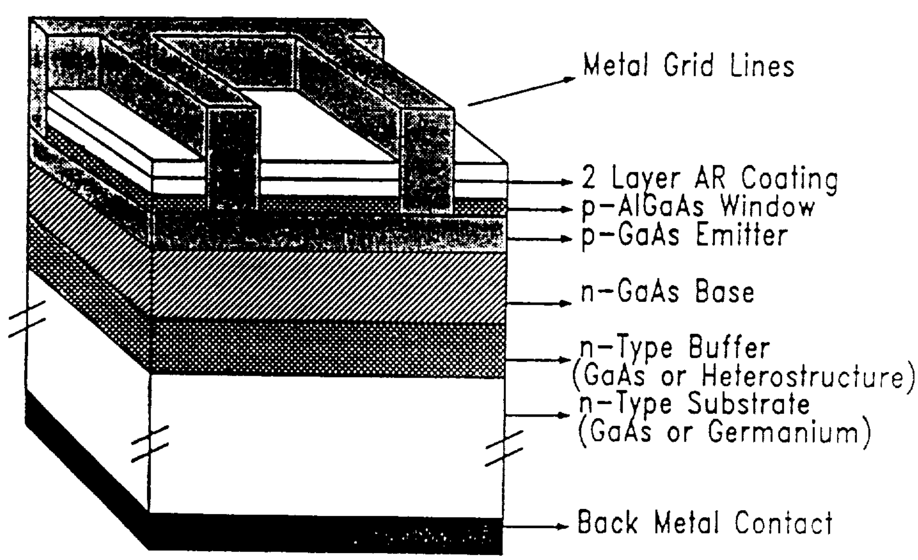

Figure 1. Structure of GaAs/GaAs or GaAs/Ge Solar Cell

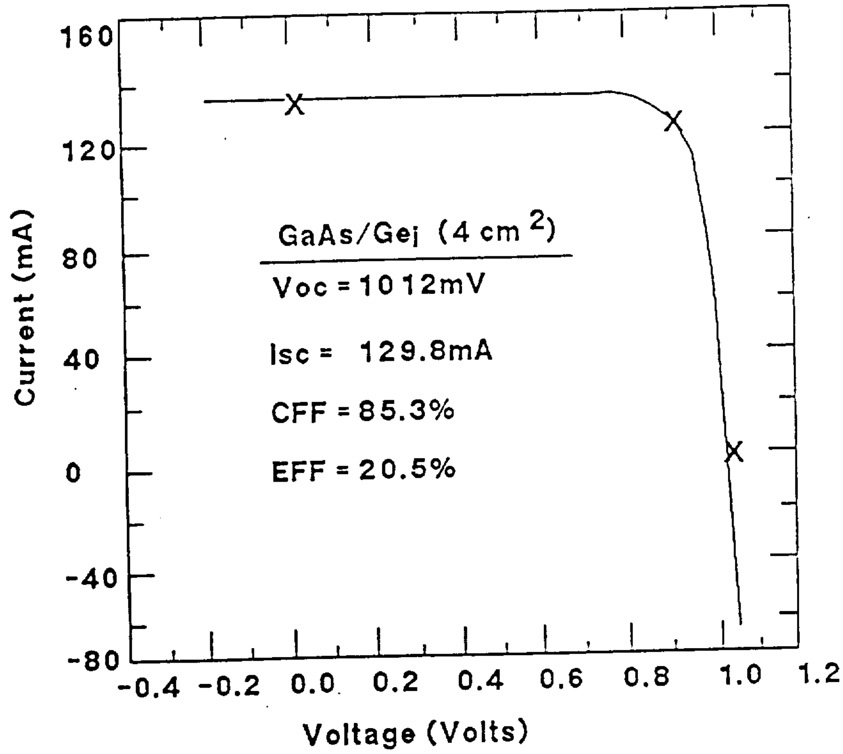

Figure 2. Photovoltaic characteristics (AMO) for GaAs/Ge (inactive) solar cell

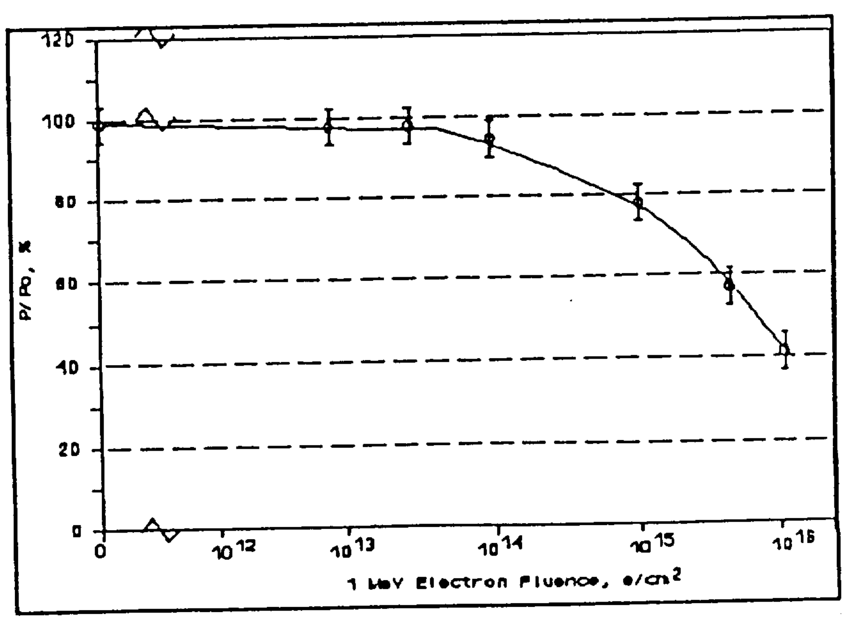

Figure 3. Relative maximum power versus 1 MeV electron fluence